Experimental Demo for Small Scale MHD Plasma Accelerator*)

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The objective of the current MHD acceleration study is to thoroughly explain the compact experimental demo of MHD accelerator and to clarify some significant plasma variables both within and at the exit of the newly introduced mullite ceramic compact channel. The significant challenge of the current study is to use the 0.4-tesla neodymium magnetic as an MHD source, while the model rocket engine (C6-0, ESTES) is introduced and employed as a gas (plasma) source. The results of present demonstrations reveal that the highest gas velocity was calculated at 117.2 m/s using the gas pressure measurement through the pitot tube. The TOF method using two photo diodes showed the slowest speed of 50 m/s.

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1. Introduction

In recent years, MHD and related works have been studied extensively in many research institutions. The most widely known applications of MHD are as a generator and as an accelerator. The study of the MHD accelerator was primarily as a promising candidate particularly for spacecraft or jet-plane propulsion systems. This is because MHD acceleration is able to produce amazingly high thrust culminating in an extremely fast exhaust gas speed. However, most of the previous studies were conducted by numerical analysis of both one-dimensional and three-dimensional calculation [1-12]. This might be because the experiments with MHD acceleration require high power and high voltage, as well as a large facility. Consequently, an extremely large budget is needed for conducting the experiments. In addition, plasma produced using MHD acceleration is generally in the high temperature regime. It is also somewhat difficult to find the appropriate materials to construct the channel for actual experiments.

The objective of the current study is to thoroughly explain the compact experimental demo of a MHD accelerator and to clarify some significant plasma variables both through the length and at the exit of the channel. Understanding the variables is fundamental for the state-of-theart MHD accelerator field of research if the principle is to be used for actual applications in the near future. Some significant variables have to be clarified and fully understood for conducting a relatively inexpensive demonstration. Designing and constructing a compact MHD channel In the analytical procedures, some measurement methods such as measuring the gas pressure, TOF using two diodes, employing the lighting detector resistor and optical measurement system are introduced for investigating the plasma behavior and parameters. Results reveal that the estimated gas velocity using the gas pressure measurement through the pitot tube gives the highest speed of gas, calculated at a value of 117.2 m/s. The TOF method using two photo diodes showed the slowest speed of 50 m/s.

The current paper is organized as follows. The explanation of how to construct the experimental setup as well as the materials to be used is presented first. Then, results of differing measurement methods and problems are investigated and discussed. Finally, the conclusion of the current experiment of a compact MHD accelerator is summarized.

is the key to an effective demonstration. Selecting appropriate material for the channel construction is also crucial. In this study, the mullite ceramic is introduced for constructing a compact channel. The mullite ceramic is selected because it is able to endure and resist a relatively high temperature, heat and shock generated by the heat. Another significant challenge in the current study was using the 0.4-tesla neodymium magnets as a MHD source. The magnets were chosen because they display considerably stronger magnetic power in a compact size as well as being relatively inexpensive. A significant highlight of the present work is the introduction of a model rocket engine (C6-0, ESTES) as a gas (plasma) source. The advantages of this model rocket engine are that it is economical, compact, and highly reliable. An additional advantage is the simplicity of electrical ignition.

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Fig. 1 The schematic view of the outline for experimental and measurement methods setup.

2. Experimental Setup

The current study investigates the fundamental parameters of gas (plasma) flow throughout the MHD channel. Mullite ceramic $7.5 \times 4.0 \times 4.0 \text{ mm}^3$ is used for the main MHD structure. This is because it is able to resist the strong shock and heat during the plasma production process, and it simplifies the construction of the of MHD channel. A pair of neodymium magnets of 0.4 Tesla is attached near the electrodes. These are to generate the magnetic field along the channel when the power supply is connected. The model rocket engine is used to supply the gas (helium) in the channel.

To initialize the model rocket engine, the ignition circuit is introduced and provided. When the power supply is turned on, the model rocket engine generates the gas flow through the channel, and the interaction of the magnetic field and the flowing gas produces the plasma. The plasma flows out at the exit of the channel. To observe the fundamental parameters of the generated plasma such as plasma temperature and velocity, the Lighting Diode Rectifier (LDR), together with the micro controller panel, is used. The experimental setup is illustrated in Fig. 1.

3. Results and Discussions

In this section, significant parameters and results of the measurements are presented.

3.1 Plasma temperature and measurement

In general, plasma temperature is measured in order to investigate how effective the plasma generation process is, because the higher the plasma temperature the more efficient the plasma generation. One may know that



Fig. 2 Optical measurement method for plasma temperature.

gas plasma temperature induced by the MHD acceleration is extremely high (more than 1800 K), therefore to measure the temperature researchers at Nob. Harada Plasmadynamics Lab in Nagaoka University of Technology recommended using the optical measurement method, shown in Fig. 2. In this figure, I_s indicates the source light intensity, while I_p indicates the intensity of light radiated by plasma. I_T is the sum of I_p and I_s .

This set of optical measuring instruments is placed 1000 mm from the exit of the small scale MHD channel. Figure 3 shows the waveform of plasma production when it is generated in the MHD channel. The red-front line is the plasma temperature. It can be seen that the estimated temperature at the stable state of plasma production is about 2000 K.

3.2 Plasma velocity estimated by gas pressure

To observe and measure the gas pressure along the channel and at the exit is significant as it is one of use-



Fig. 3 Plasma temperature and waveform.



Fig. 4 TOF using 2 photo diodes measurement.

ful parameters to ultimately estimate the gas velocity. The gas pressure is measured using the differential manometer(Okano works Ltd, DMC-203N) and a Pitot tube (Okano works Ltd, LK-00). According to the values shown on the screen of the differential manometer, the dynamic pressure is equal to the total pressure subtracts the static pressure. A maximum value of gas pressure of 0.7 kPa is observed and measured. During the measurement, the Pitot tube is melted and bended after the measurement. This is because the temperature of the gas is considerably high, so the material made of the Pitot tube is not able to resist and endure (it may exceed 1800 K). To estimate the gas velocity at the exit of the channel, this following expression is used.

$$V = C \sqrt{\frac{2P_{\rm d}}{\rho}},\tag{1}$$

where V is gas velocity, P_d is dynamic pressure, C is Pitot tube coefficient, while ρ is fluid density. Using this estimation, the gas velocity of 117.2 m/s is calculated.

3.3 Plasma velocity estimated using a photo diode

In this section, the result of estimated gas velocity is presented. In the measuring process, the TOF using 2 photo diodes is used as shown in Fig. 4.

Distance from the channel to measuring system	Gas velocity
1.5 cm (1^{st} attempted)	112.71 m/s
1.5 cm (2 nd attempted)	116.50 m/s
3 cm (1 st attempted)	92.63 m/s
$3 \text{ cm} (2^{nd} \text{ attempted})$	93.04 m/s

Table 1 shows gas velocity at differing measurement positions.

The velocity is calculated using the distance between the two diodes over the recorded time when the gas (plasma) reaches the diode. If the distance between two diodes is 0.02 m, and the gas (plasma) takes 0.0004 s drifting from the first diode to the other, the velocity of 50 m/s is calculated.

3.4 Plasma velocity estimated using lighting detector resistor

The LDR at the darkroom is used to calculate the plasma velocity. This is based on the assumption that a spark may occur in the MHD channel when the gas is ionized in the plasma producing process. Therefore, two sets of LDR are placed at the exit of the channel. However, to calculate the velocity, the distance of each LDR needs to be set. The distance of 20 cm is designated. The micro controller circuit board is introduced in order to record the trigger time of each LDR. The distance from the edge of the channel where the plasma flows out also needs to be designed.

In the current experiments, 2 values and positions, namely 3 cm and 1.5 cm from the edge of the channel, are experimented with and investigated. To prevent inadvertent under-or-over estimating velocity, each measurement is conducted twice. After the first attempt (1st attempt), we recorded the calculated velocity. Then, the second attempt (2nd attempt) was conducted and the velocity recorded at the same position. The velocity results are shown in Table 1.

In addition, the photo of gas plasma while flowing out of the MHD channel is also recorded and is shown as in Fig. 5

It can be seen that the gas plasma disperses randomly. This may be one of the reasons why the first recorded plasma velocity is not equal to that of the second recorded velocity. However, the recorded velocity at two different positions seems to be acceptable, since it does not show a significant difference. Another factor may be because the experiments were conducted in a room where the light intensity was not controlled. Therefore, the light or a flickering lamp may have caused the errors.



Fig. 5 Photo of plasma generation using small scale MHD channel.

4. Conclusions

The current study has presented the experimental concept for MHD acceleration and its fundamental results. With the collaboration of Nagaoka University of Technology, the mullite ceramic was recommended for the construction of the channel, and the neodymium magnets of 0.4 Tesla were attached thereto. To observe the plasma temperature generated in the MHD channel, the optical measurement method was used. Results revealed that the plasma temperature was approximately 2000 K. The gas velocity at the exit of the MHD channel was also investigated. Results showed that the gas velocity estimated using the gas pressure measurement through the pitot tube gave the highest speed of the gas. The value of 117.2 m/s was calculated. The TOF method using two photo diodes showed the slowest speed of 50 m/s. Estimating the gas velocity using the LDR, which is controlled by the micro controller circuit, also showed acceptable results. The difference from the value observed by the gas pressure measurement and estimation was not so significant. This small scale experimental demo could be valid for investigating the fundamental parameters of MHD acceleration.

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